



Invited Plenary Abstract

P12

Why bones break – the material and structural basis of bone strength and fragility

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The propensity to fracture is governed by the ratio of maximum strength of bone and the loads applied to the skeleton during normal activities. The contribution of external loads to reductions in this safety factor cannot be ignored because small increases in loading due to objects carried in front of the body, for example, create disproportionately large joint moments at the vertebral bodies. Bone itself must achieve an adequate safety factor while minimising the energy cost of movement. That is, a trade off between strength and lightness. Cortical bone must also achieve sufficient stiffness to act as an efficient lever, without becoming excessively brittle, a trade off between stiffness and toughness. Cancellous bone is weaker than cortical bone, but more flexible, allowing it to act as an efficient shock absorber. The hierarchical structure of these two forms of bone allows stiffness to be achieved in the former by an architecture that arrests cracks and prevents their propagation (toughness); and in the latter dissipating energy through greater deformation and microdamage, allowing recovery of structure rather than failure and compaction of the shock absorber. The strength and stiffness of bones *per se* depend on the strength and stiffness of their material, and the build of the whole bone structure. This offers three possible mechanisms to reduce their risk of fracture. First, increase bone mass – larger bones can resist greater loads. Second, distribute that mass most effectively – a small addition to bone mass can substantially increase bending and torsional strength if placed strategically. Third, improve the material properties of the bone tissue – make the bone matrix, itself, stronger or capable of absorbing more energy. Adding, or redistributing, bone mass influences structural properties, affecting the behaviour of bones as an organ. Alterations in the bone material are manifested in the mechanical properties of bone per unit volume, reflected in measures of stress, strain, modulus of elasticity and modulus of toughness. The influence of such factors that affect bone fragility, but are not accounted for by bone mass, or quantity, has been termed bone quality. It is argued that these variables explain the disparity between the change in BMD and the reduction in fracture risk in response to treatment. Although they are necessary to understand a bone's risk of fracture, they are more inscrutable than mass to measure *in vivo*. Such factors include mineral density, maturation and chemical composition; collagen structure and biochemistry; osteocyte viability; tissue microdamage; and, micro-architecture. The technologies to extract quantitative measures of bone quality for assessment of fracture risk are emerging, but embryonic. Greater understanding of the material properties of bone, and its interaction with structure, will ultimately improve the assessment of fracture risk and monitoring of patients being treated for metabolic bone disease.